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MEMORANDUM REPORT No. 944

An Exploratory Study Of The Initiation Of Steel-Shielded Composition "B" By Shaped Charge Jets (U)

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DEPARTMENT OF THE ARMY PROJECT No. 5B0304009

ORDNANCE RESEARCH AND DEVELOPMENT PROJECT No. TB3-0134

BALLISTIC RESEARCH LABORATORIES

ABERDEEN PROVING GROUND, MARYLAND

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MEMORANDUM REPORT NO. 944

OCTOBER 1955

AN EXPLORATORY STUDY OF THE INITIATION OF STEEL-SHIELDED COMPOSITION "B" BY SHAPED CHARGE JETS (U)

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MEMORANDUM REPORT NO. 944

LZernow/ILieberman/SKronman/sdb
Aberdeen Proving Ground, Maryland
October 1955

AN EXPLORATORY STUDY OF THE INITIATION OF STEEL-SHIELDED COMPOSITION "B" BY SHAPED CHARGE JETS (U)

ABSTRACT

A preliminary study of the initiation by shaped charge jets of Comp "B" charges protected by various thicknesses of steel coverplates has been carried out. The aim was to determine the variables in the experiment which are likely to have a significant effect. High speed photographic techniques were used to ascertain details of the initiation process.

The effects of length of explosive charge, thickness of coverplate and various types of explosive confinement were explored. Both M9A1 and 105mm charges were used as the source of the jet in these experiments.

Several hypotheses regarding the nature of the mechanism of the initiation process are proposed as a basis for additional studies.

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INTRODUCTION

The initiation of high explosives by high velocity fragments is an important consideration in assessing vulnerability of warheads containing high explosive. The jet from a shaped charge constitutes a rather specialized form of high velocity fragments, whose ability to initiate high explosive has intrinsic interest even though the specifications of the detailed fragment characteristics are more nebulous than would be desirable for an experiment with single fragments. The fragment velocity which can be achieved with shaped charges is, however, considerably greater than that obtainable with other available techniques.

From simple considerations one would expect that explosive confinement and protective coverplate thickness would be important variables. It was anticipated that other important variables might become apparent in the course of the experiment. Explosive length turned out to be such a variable.

CHARACTERISTICS OF THE SHAPED CHARGE JETS USED

The jets used in these experiments were obtained from two types of shaped charges: the M9A1 charge (nominal) as shown in Figure 1, and the 105mm charge as shown in Figure 2. The cones in both cases were made of copper. The appearance of the jets from these charges are shown in Figures 3 and 4. Computed velocities of the tip of the jet at the interface of jet and steel target as a function of the depth of penetration are shown in Figures 5 and 6.

The M9A1 size was used mainly for the high speed photographic observations, although quite a few were used in carrying out the parallel studies of the effects of confinement, charge length and charge diameter. The 105mm size (approximately twice the diameter of the M9A1) was used for the study of the effects of confinement and charge length.

EXPERIMENTAL PROCEDURE

The general experimental procedure consisted of firing a shaped charge jet through a protective steel coverplate into a piece of high explosive fastened to the rear of the coverplate.

1. Explosive Charge Preparation

Explosive charges of Composition "B" were cast in cylindrical form. Charges of both 1-1/2" and 3" diameters were prepared. Charge lengths were varied from 1" to 15" and were made up of increments varying in length from 1" to 6". There appears to be no evidence in all of the experiments that a single homogeneous cylinder of high explosive behaves appreciably differently from a similar cylinder made up of increments. Long incremental charges are likely to be more nearly homogeneous in composition than long single-piece charges because of the increased probability of segregation in the one-piece charge.

2. Protective Coverplate

For the experiments with 105mm charges, the coverplate thickness varied from 0" to 12" of 1020 mild steel. The coverplate thickness was increased in 3" increments by stacking 6" x 6" x 3" steel blocks.

The 105mm shaped charge was fired at a standoff of 7-1/4" from the outer coverplate surface, as shown in Figure 7. The explosive charge was held in physical contact with the inner coverplate surface.

The experiments with the M9A1 charge were carried out with coverplate of 1020 mild steel varying from 0" to 3" in thickness.

3. Confinement of Explosive Charge

In a separate phase of the experiment the explosive charge was confined by a second plate on the opposite side of the charge, as shown in Figure 8.

An additional experiment with the 105mm charge was carried out with the 3" diameter explosive charge encased in a steel body having a 3/8" wall thickness. It was also confined at the open end as in Figure 8.

For the M9A1 charge, the 1-1/2" diameter explosive cylinders were encased in 1/8" steel tubing for the confinement experiments. The end coverplate (3" of 1020 mild steel) was also used.

4. Photographic Observation

In order to locate the point of initiation within the explosive charge as the coverplate thickness was increased an ultra high speed framing camera was used to observe the location of the emerging detonation wave. From this observation one can approximate the interior point of initiation.

In addition, one could observe the behavior of those explosive charges which failed to be initiated immediately. In many of these observations, the luminosity of the air shock from the detonating explosive provided the necessary lighting. In some instances, backlighting was provided by an argon bomb.

EXPERIMENTAL DATA

The observations made with the 105mm shaped charges are recorded in Tables I, II, and III.

Table I gives the results for 3" diameter cylinders of explosive (Comp "B") with lengths varying from 1" to 15" and coverplate thicknesses varying from 0" to 12" of 1020 mild steel. In this phase, no confinement was used. Figure 7 shows the experimental set-up.

Similarly, Tables II and III give data for the two phases involving confinement.

TABLE I

PERCENTAGE OF HIGH ORDER INITIATIONS OBTAINED WITH VARIOUS LENGTHS (L) OF 3" DIAMETER COMP "B" CYLINDERS INTO WHICH A 105MM SHAPED CHARGE JET WAS FIRED THROUGH VARIOUS THICKNESSES OF STEEL COVERPLATE (t) WITHOUT END CONFINEMENT

Coverplate Thickness t in inches \ Explosive Length L in inches	1	3	6	9	12	15
0	(5) 100%					
3	(5) 20%					
6	(5) 0%	(4) 100%				
9		(5) 20%	(5) 60%	(5) 80%		
12		(5) 20%	(5) 40%	(5) 60%	(5) 80%	(4) 100%

In this table and subsequent tables the number in parenthesis represents the number of trials with the particular charge length and coverplate thickness.

In the absence of photographic observations, high order initiation is recorded if there is a dent in the coverplate (or confining plate) adjacent to the charge as shown in Figures 9 and 10. These show the observed variations in the dent on the steel coverplate which were recorded as high order initiation. In the M9A1 experiments photographic observations also were made which are consistent with the dent criterion for high order initiation.

TABLE II

PERCENTAGE OF HIGH ORDER INITIATIONS OBTAINED WITH VARIOUS LENGTHS (L) OF 3" DIAMETER COMPOSITION "B" CYLINDERS INTO WHICH A 105MM SHAPED CHARGE JET WAS FIRED THROUGH VARIOUS THICKNESSES OF STEEL COVERPLATE (t) WITH 3" 1020 MILD STEEL END CONFINEMENT

Cover plate Thickness t (in inches) \ Explosive Length L (in inches)	1	3	6	9	12
0	(5) 100%				
3	(5) 60%	(5) 100%			
6	(29) 14%	(5) 100%	(5) 100%	(5) 100%	(5) 100%
9	(5) 0%	(5) 80%	(5) 80%	(5) 100%	(5) 100%
12	(5) 20%	(5) 20%	(5) 60%	(5) 60%	(5) 60%

TABLE III

PERCENTAGE OF HIGH ORDER INITIATIONS OBTAINED WITH VARIOUS LENGTHS (L) OF CASED 3" DIAMETER COMP "B" CYLINDERS INTO WHICH A 105MM SHAPED CHARGE JET WAS FIRED THROUGH VARIOUS THICKNESSES OF STEEL COVERPLATE (t) WITH 3" 1020 MILD STEEL END CONFINEMENT, CASING STEEL, 3/8" WALL THICKNESS

Cover plate Thickness t in inches \ Explosive Length L in inches	1	3	6	9	12	15
3	(5) 100%					
6	(5) 20%	(5) 100%				
9	(5) 0%	(5) 100%				
12	(5) 0%	(5) 20%	(5) 80%	(5) 40%	(5) 80%	(4) [illegible]

The M9A1 experimental results are collected in Tables IV, V, VI, and VII. Table IV shows the results (on unconfined explosive) which were observed photographically.

TABLE IV

PERCENTAGE OF HIGH ORDER INITIATIONS OBTAINED WITH VARIOUS LENGTHS (L) OF 1.5" DIAMETER COMP "B" CYLINDERS INTO WHICH AN M9A1 SHAPED CHARGE JET WAS FIRED THROUGH VARIOUS THICKNESSES OF 1020 MILD STEEL COVERPLATE (t). OBSERVATIONS WERE MADE WITH THE ULTRA HIGH SPEED FRAMING CAMERA.

Cover plate Thickness t in inches \ Explosive Length L in inches	1	2	3
0	(3) 100%		
1/16	(5) 100%		
1/2	(5) 100%		
1	(5) 100%		
2	(5) 20%	(5) 100%	
3	(5) 0%	(2) 0%	([illegible]) 0%

TABLE V

PERCENTAGE OF HIGH ORDER INITIATIONS OBTAINED WITH VARIOUS LENGTHS (L) OF 1.5" DIAMETER COMP "B" CYLINDERS INTO WHICH AN M9A1 SHAPED CHARGE JET WAS FIRED THROUGH A 3" THICKNESS OF 1020 MILD STEEL COVERPLATE (t) WITH 3" 1020 MILD STEEL END CONFINEMENT.

PHOTOGRAPHIC OBSERVATIONS WERE MADE ON THE 2" LENGTH OF CHARGE.

Explosive Length L in inches	% of High Order Initiation
2	(8) * 87%
3	(3) 67%
4	(10) 30%
5	(10) 10%
8	(5) 40%
10	(5) 20%
12	(5) 60%

* 5 rounds only were photographically observed. These rounds had 1" end confinement plates (1020 mild steel) in place of the 3" plate normally used.

TABLE VI

PERCENTAGE OF HIGH ORDER INITIATIONS OBTAINED WITH VARIOUS LENGTHS (L) OF 1.5" DIAMETER COMP "B" CYLINDERS ENCASED IN A 1/8" STEEL BODY INTO WHICH AN M9A1 SHAPED CHARGE JET WAS FIRED THROUGH A 3" THICKNESS 1020 MILD STEEL COVERPLATE (t) WITH 3" 1020 MILD STEEL END CONFINEMENT

Explosive Length L in inches	% of High Order Initiations
1	(5) 60%
2	(5) 100%
4	(5) 100%
6	(5) 100%
8	(5) 100%
10	(5) 100%

TABLE VII

PERCENTAGE OF HIGH ORDER INITIATIONS OBTAINED WITH VARIOUS LENGTHS (L) OF 3" DIAMETER COMPOSITION B CYLINDERS INTO WHICH AN M9A1 SHAPED CHARGE JET WAS FIRED THROUGH A 3" THICKNESS OF 1020 MILD STEEL COVERPLATE (t) WITH 3" 1020 MILD STEEL END CONFINEMENT.

Explosive Length L in inches	% of High Order Initiations
5	(8) 87%
8	(10) 60%

ANALYSIS OF RESULTS

A. M9A1 Charges - Photographic Observations

The Beckman & Whitley ultra high speed framing camera was used to study the initiation of the high explosive, with the M9A1 copper cone being fired into 1-1/2" diameter cylinders of Comp "B".

These results will be considered first since they will suggest a basis for analyzing the 105mm data, which were obtained without photographic observations. Table IV shows the conditions studied.

The initiation of an uncovered Comp "B" cylinder 1" long is shown in Figure 11. The jet is seen striking the left face of the target. Initiation is seen to occur very near the surface of the Comp B, on the basis of the shape of the emerging side air shock. The detonation propagates to the right. The shape of the detonation wave is approximately spherical as can be seen from the shape of the air shock emerging from the right face of the explosive.

The initiation through a 1/16" coverplate is quite similar in appearance, as is shown in Figure 12.

When the coverplate is 1/2" thick, we see in Figure 13 evidence of initiation about 1/2" deep in the explosive (see frames 6 and 7).

For a 1" steel coverplate and a 1" long explosive cylinder, shown in Figure 14, the point of initiation is judged to be about 3/4" from the steel-explosive interface. There is evidence of asymmetry in the emerging side air shock which suggests that the initiation was not along the axis of the cylinder but rather nearer the side surface facing the camera. (see frame 2). The peculiar behavior of the detonation proceeding backward is noteworthy, since it appears to indicate an erratic development of the backward wave front.

A 2" steel coverplate on a 1" long explosive cylinder gives the results shown in Figure 15. Here it is clear that initiation is occurring asymmetrically and originates very near the free face of the explosive. (see frame 3). Again the erratic development of the backward

going detonation wave is seen (in frames 5, 6 & 7). There is even evidence for a Mach interaction between two different portions of the backward moving detonation wave (see frames 8 and 9).

With 2" of coverplate and 1" of Comp B, failures to initiate high order were observed 4 times out of 5. Figure 16 shows the photograph of such a failure to initiate. It should be pointed out that it is extremely rare that any unconsumed high explosive is recovered, so that even though high order initiation does not occur, the explosive is burned. So far no photographic evidence has been obtained of either the deflagration or the low order detonation which is presumed to be responsible for the consumption of the high explosive.

Initiation of a 2" length of Comp "B" through 2" of steel coverplate is seen in Figure 17. Here again, initiation is seen to occur asymmetrically. The point of initiation is estimated from frame 1 to be about 1/4" into the 2nd cylinder. The erratic backward going detonation is again seen in frames 2, 3 and 4.

Failure to initiate a 2" length of charge through a 3" coverplate is shown in Figure 18.

These results appear to indicate a progressive movement of the point of initiation deeper into the high explosive as the coverplate thickness is increased.

The M9A1 experimental data with end confined explosive charges, which are given in Table V, have already been described as erratic. It was thought that high speed photography might indicate some reason for this behavior.

Figure 19 shows the initiation of a 2" length of explosive sandwiched between a 3" steel coverplate and a 1" steel end-confining plate. The initiation is clearly occurring at the far interface, which is being struck by the jet after it pierces the front coverplate and the explosive itself. The development of the backward moving detonation is accompanied by a rather unusual display of illumination which may indicate low order

detonation in the portion of the explosive which has already been traversed by the jet.

It is suggested that the unexpected peak in the percentage of high order initiation for the short lengths of Comp "B" with end confinement may be due to the fact that the M9A1 jets showed (see radiograph in Figure 3) hooks and a curved portion on the front which, by providing a larger impact area on the second or confining plate, would be likely to increase the probability of initiation at the back plate. This effect furthermore would be more pronounced for the thinner coverplates, which would not wipe off the entire hook during penetration as much as would a thick coverplate. This hypothesis should be tested in further investigations.

Pertinent data from experiments with 1/8" steel cased Comp B charges (Table VI), increased diameter (3") Comp B charges (Table VII), no confinement (Table IV) and end confinement (Table V) are summarized in Table VIII below to indicate the trend toward higher initiation probability with confinement and with increasing diameter.

TABLE VIII

% OF HIGH ORDER INITIATIONS
COVERPLATE 3" THICK FOR ALL SHOTS

Conditions	Unconfined 1-1/2" Dia.	Confined 1/8" Steel Case End 1-1/2" Dia.
1" Length Comp B	0%	60%
	End Confined Only	
	1-1/2" Dia.	3" Dia.
5" Length Comp B	10%	87%
8" Length Comp B	40%	60%

B. 105mm Experiments

1. Unconfined Charges of Comp "B" in Contact with the Coverplate.

It is evident from Table I that for a given explosive length, as the protective coverplate thickness increases, the probability of high order initiation decreases. Furthermore, for a given coverplate thickness as the explosive length increases, the probability of high order initiation increases. Thus the results suggest a series of relationships shown schematically in Figures 20, 21 and 22. Figure 20 shows the parameters, L_1 and L_2, defined as follows:

For a given thickness of coverplate,

L_1 is the explosive length such that no high order initiations will occur if the charge is L_1 or less in length,

L_2 is the explosive length such that 100% high order initiation will occur if the explosive is L_2 or more in length. The suggested relationships between percentages of high order initiations and the explosive and coverplate parameters are schematically represented in Figures 21 and 22.

2. End Confined and Fully Confined Charges of Comp "B".

The results shown in Table II when compared with those in Table I indicate that end confinement generally increases the probability of high order initiation over that observed with unconfined charges. The results shown in Table III also suggest an increased probability of initiation for cased charges over that for unconfined charges. For the 3", 6" and 9" coverplate thicknesses the observed results for the shorter explosive targets are summarized below in Table IX.

TABLE IX

% OF HIGH ORDER INITIATIONS OBSERVED UNDER VARIOUS CONDITIONS OF CONFINEMENT

Conditions	Unconfined	End Confined	Fully Confined
3" Coverplate 1" Explosive	20%	60%	100%
6" Coverplate 1" Explosive	0%	14%	20%
9" Coverplate 3" Explosive	20%	80%	100%

It should be pointed out that with the small sample sizes to which an exploratory investigation is necessarily limited, the statistical analysis is somewhat inconclusive and that in those portions of the experiment involving thick coverplates and long explosive charges the data do not support the conclusion that confinement increases the probability of initiation.

COMMENTS ON THE INITIATION MECHANISM

It is generally agreed that one of the important initiating mechanisms is likely to be the shock wave in the explosive caused by the impact of the jet.

Increased coverplate thickness reduces the emerging jet velocity and hence decreases the shock wave amplitude. This would be expected to reduce the probability of initiation. The observation requiring further analysis is the apparent shifting of the point of initiation deeper into the high explosive as the coverplate thickness is increased. It would be useful in exploring this phenomenon further, to use jets whose tip velocity was controllable. A large number of photographic observations of the point of initiation for various conditions would also be helpful.

An hypothesis which suggests itself is that of a uniform distribution of initiation nuclei (e.g. air bubbles) in the high explosive. Since reduced shock wave amplitude reduces the probability of initiation at any nucleus, the slower jet would have to travel farther on the average

before it would initiate the explosive at one of the nuclei. We would then expect a distribution of initiation locations whose nature would be determined by the rapidity with which the initiation probability for a single nucleus falls with reduction in shock amplitude.

The nature of the relation between shock amplitude and single nucleus initiation probability could also account for the very great dispersion in the data for thick targets and long explosive charges.

An extension of this simple hypothesis would presuppose a uniform spatial distribution of initiation nuclei which also were variable in their threshold of sensitivity (e.g. air bubbles of varying dimensions). One would then have to study the probability of encountering an initiation nucleus capable of being initiated by a shock pressure which was decreasing as the depth of penetration of the jet into the explosive increased.

Explosive charge confinement and increased explosive diameter would be expected to result in an increased probability of earlier initiation since the returning boundary reflected rarefaction wave which reduces the shock amplitude is longer delayed and hence the shock pressure stays higher longer.

The possibility of other initiation mechanisms should not be ignored expecially for the slow jets moving into long explosive charges. A direct thermal transfer mechanism may be worth studying.

SUMMARY AND CONCLUSIONS

The significant variables in an experiment designed for the study of initiation of high explosives by shaped charge jets appear to be the following:

1. Thickness of coverplate.
2. Length of the explosive charge.
3. Type and degree of confinement of the explosive charge.

Suggested empirical relationships between the initiation probability and the important variables are outlined in Figures 20, 21 and 22 on the basis of the trends seen in the present data.

If one disregards the scattered data for thick coverplates and long explosive charges, conclusions may be drawn about the relation between length of the explosive charge and thickness of the coverplate. It appears from the remaining data that in the regions where the transition between 0% and 100% initiations occur, coverplate thickness for a fixed charge length decreases the initiation probability. Furthermore, for a fixed coverplate thickness, increased length of explosive charge increases the probability of initiation.

The effects of confinement are less clearly seen but the trend appears to be toward increased probability of initiation with increased confinement.

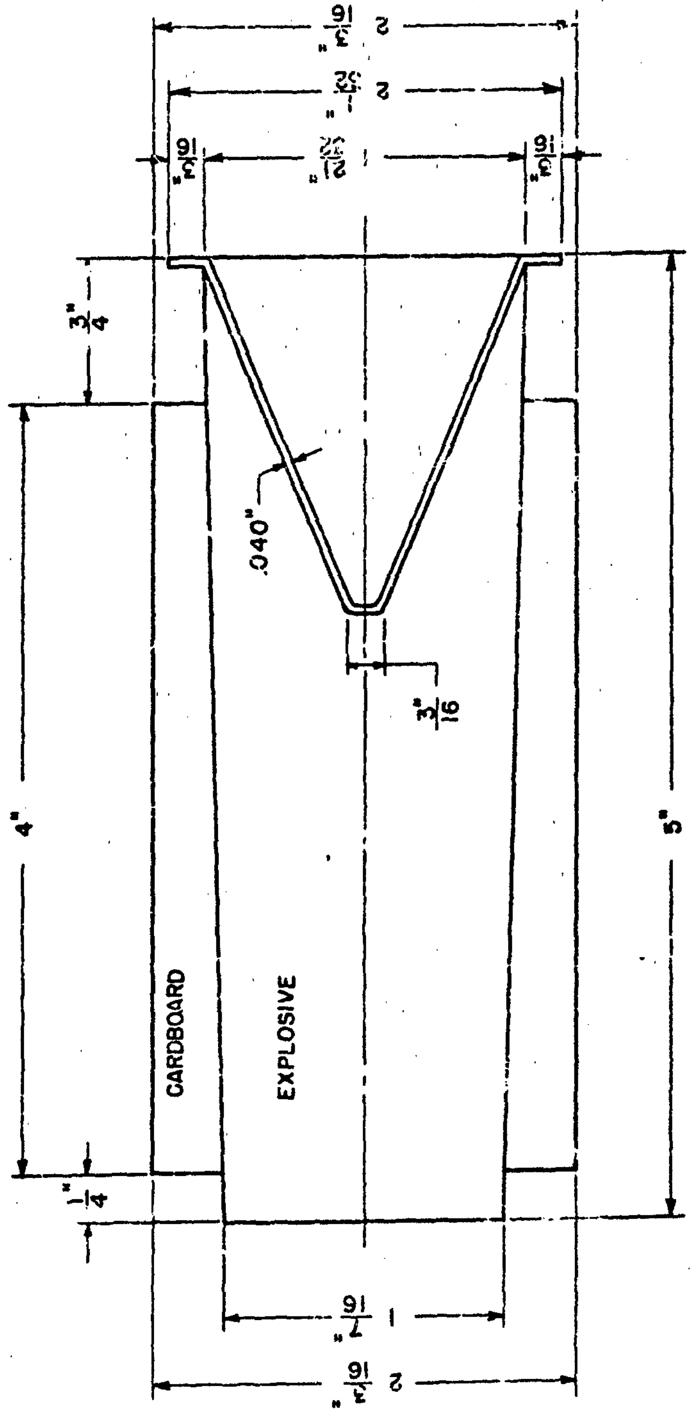
L. ZERNOW

I. Lieberman

I. LIEBERMAN

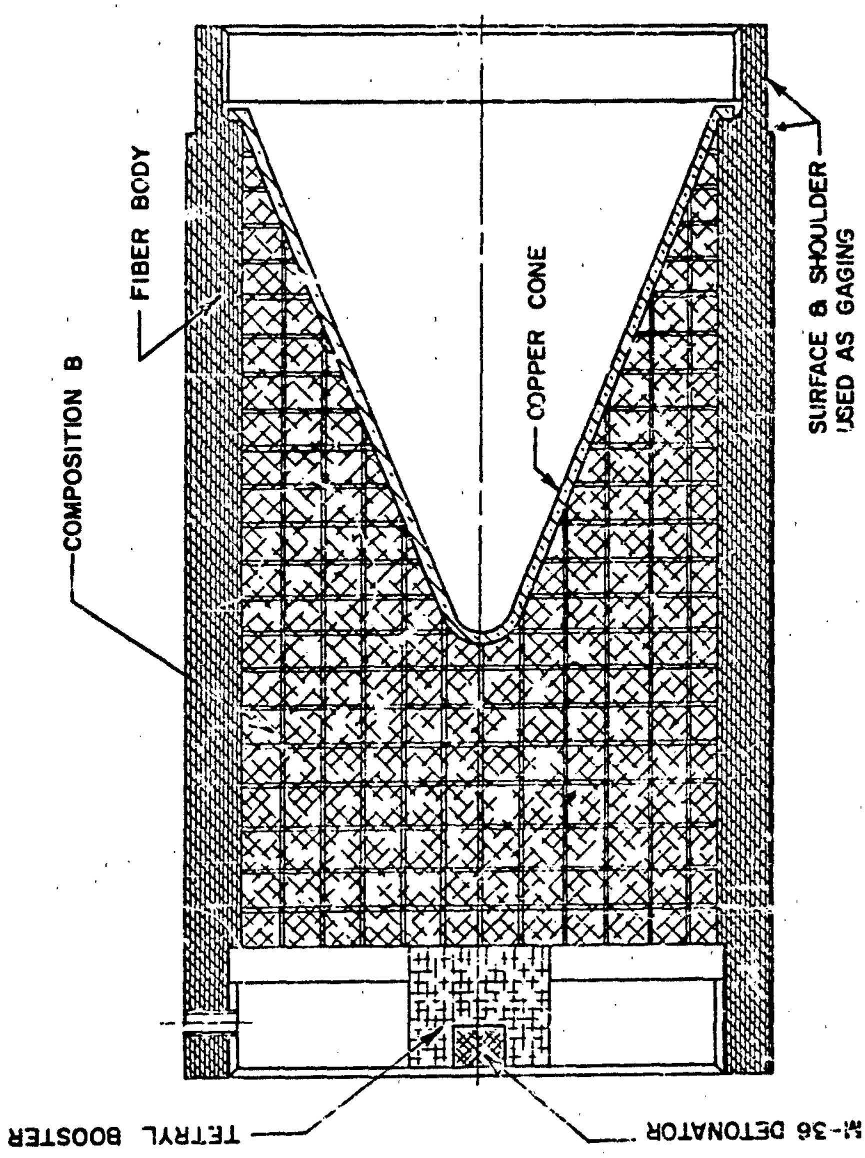
S. Kronman

S. KRONMAN



CONFIGURATION OF THE M9A1 (NOMINAL) SHAPED CHARGE

FIGURE 1



105MM FIBER-CASED CHARGE

FIGURE 2

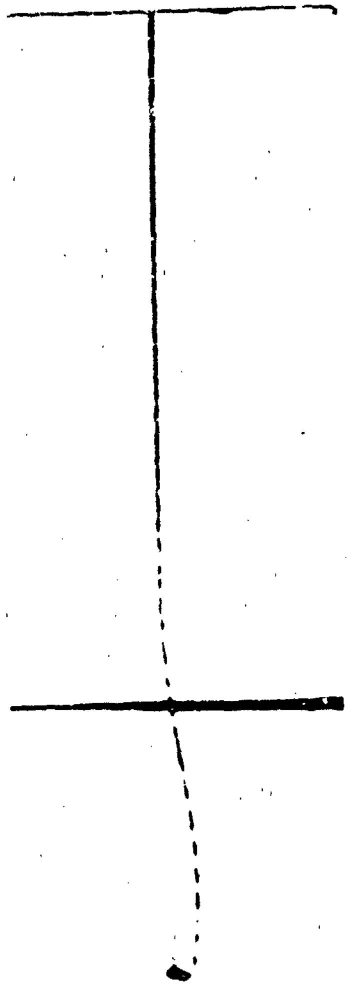
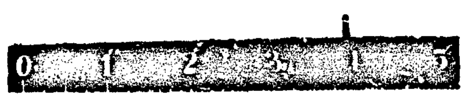


FIG. 3. Radiograph of Jet from an M9A1 Charge



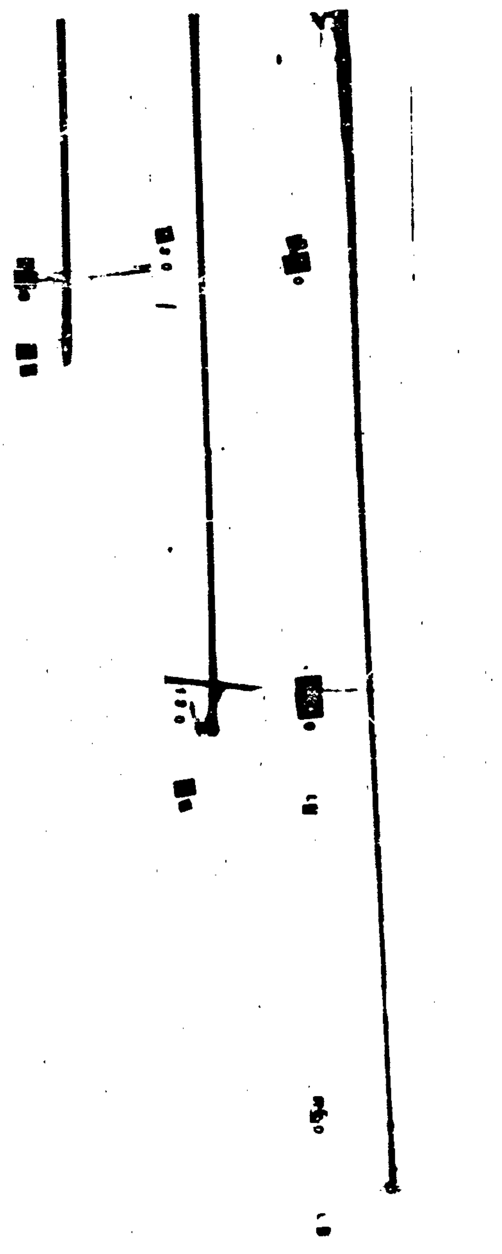


FIG. 4a. Radiographs of Jets from 105MM Charges Short Stand-off

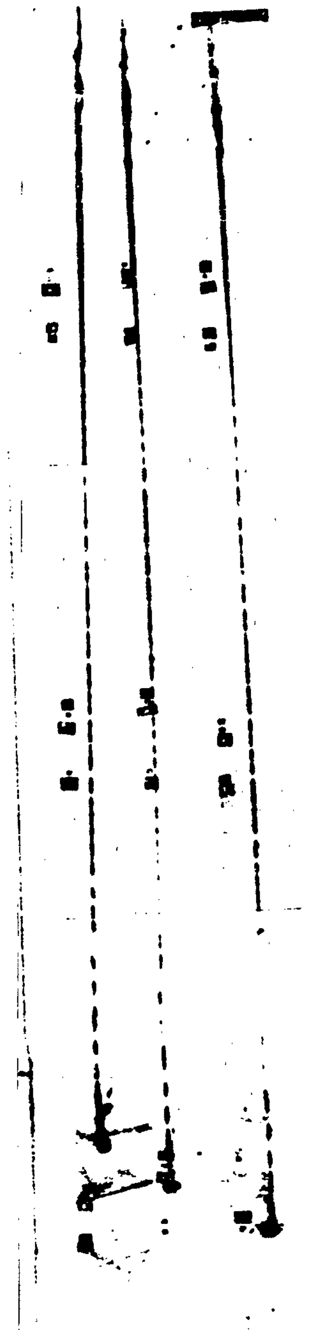


FIG. 4b. Radiographs of Jets from 105MM Charges Long Standoff

COMPUTED VELOCITY OF JET TIP FROM A 105MM CHARGE AS A FUNCTION OF THE DEPTH OF PENETRATION OF THE JET INTO STEEL.

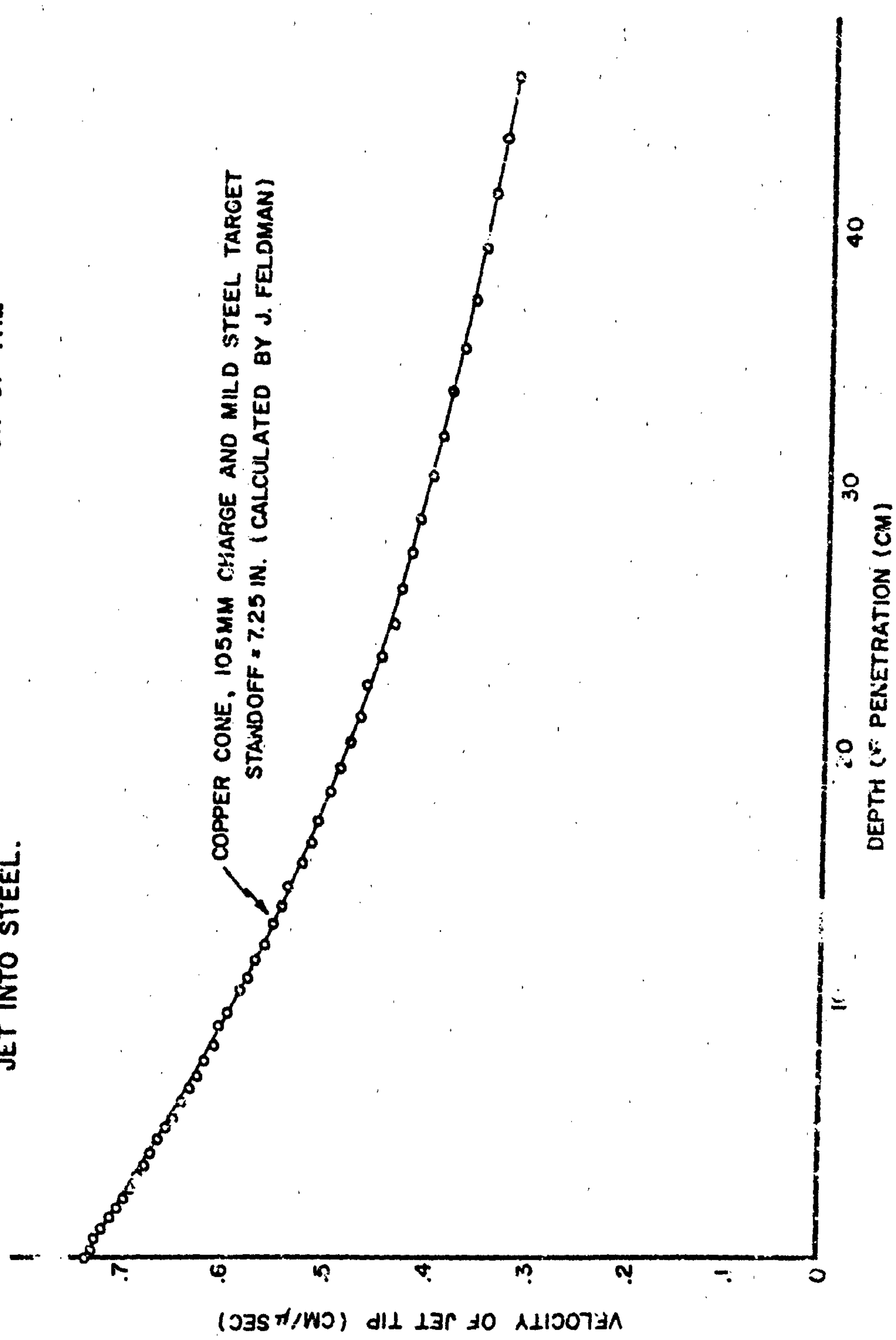


FIGURE 5

COMPUTED VELOCITY OF JET TIP FROM AN M9A1 CHARGE AS A FUNCTION OF THE DEPTH OF PENETRATION OF THE JET INTO STEEL.

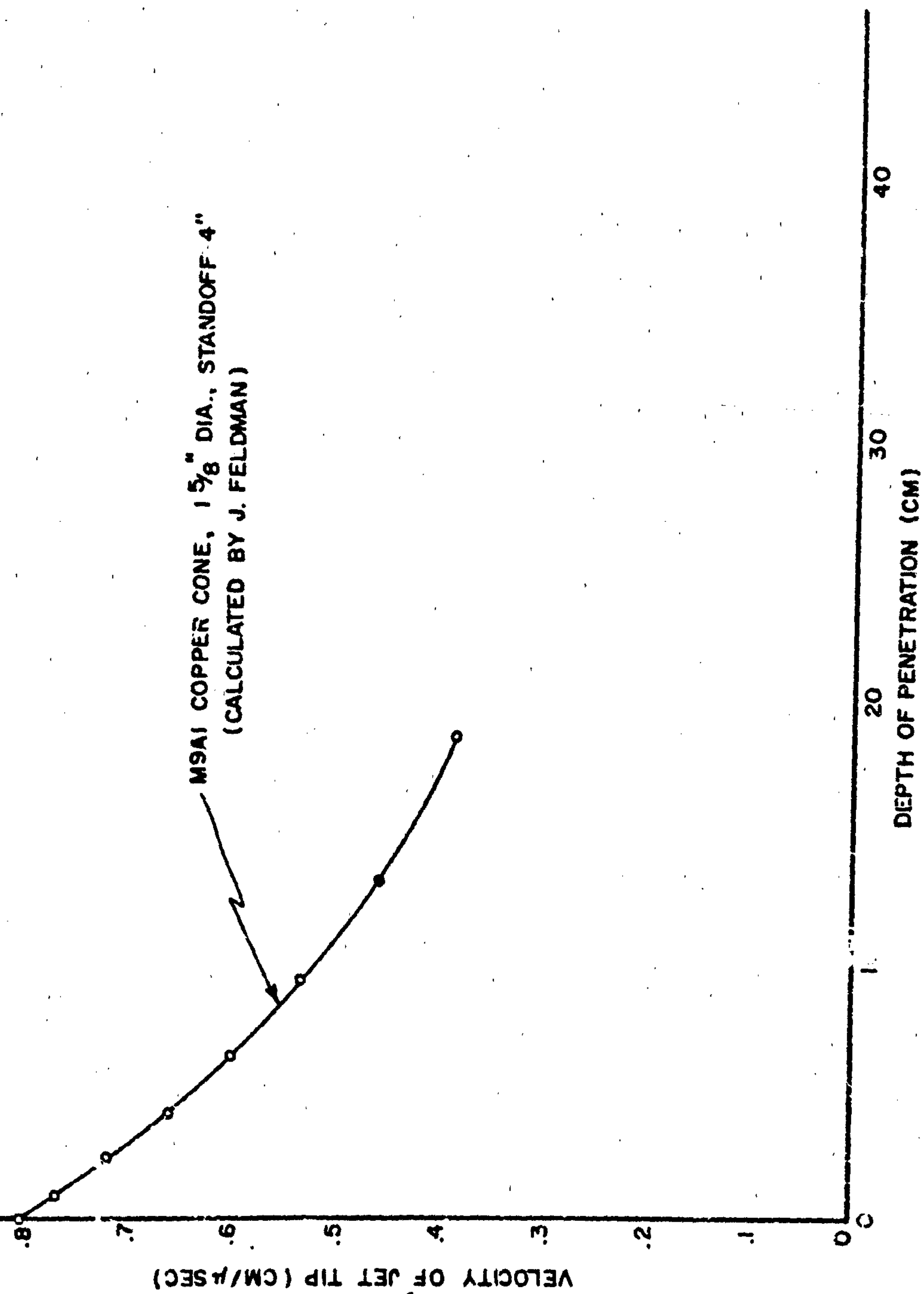


FIGURE 6

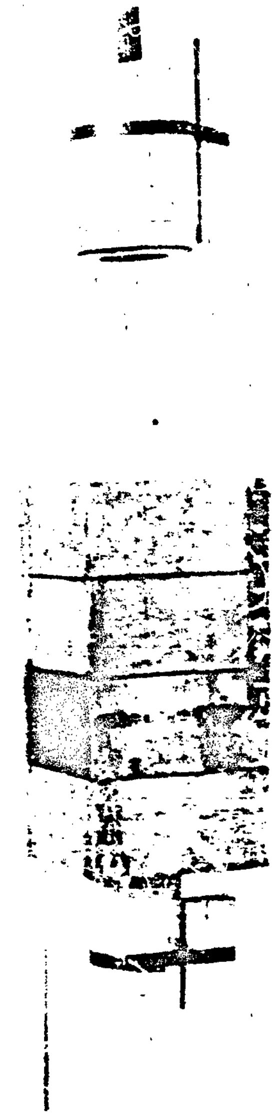


FIG. 7. Arrangement for Firing 105MM Shaped Charge Jets Through Steel Cover Plate Into Composition B Charges. W/O Confinement.

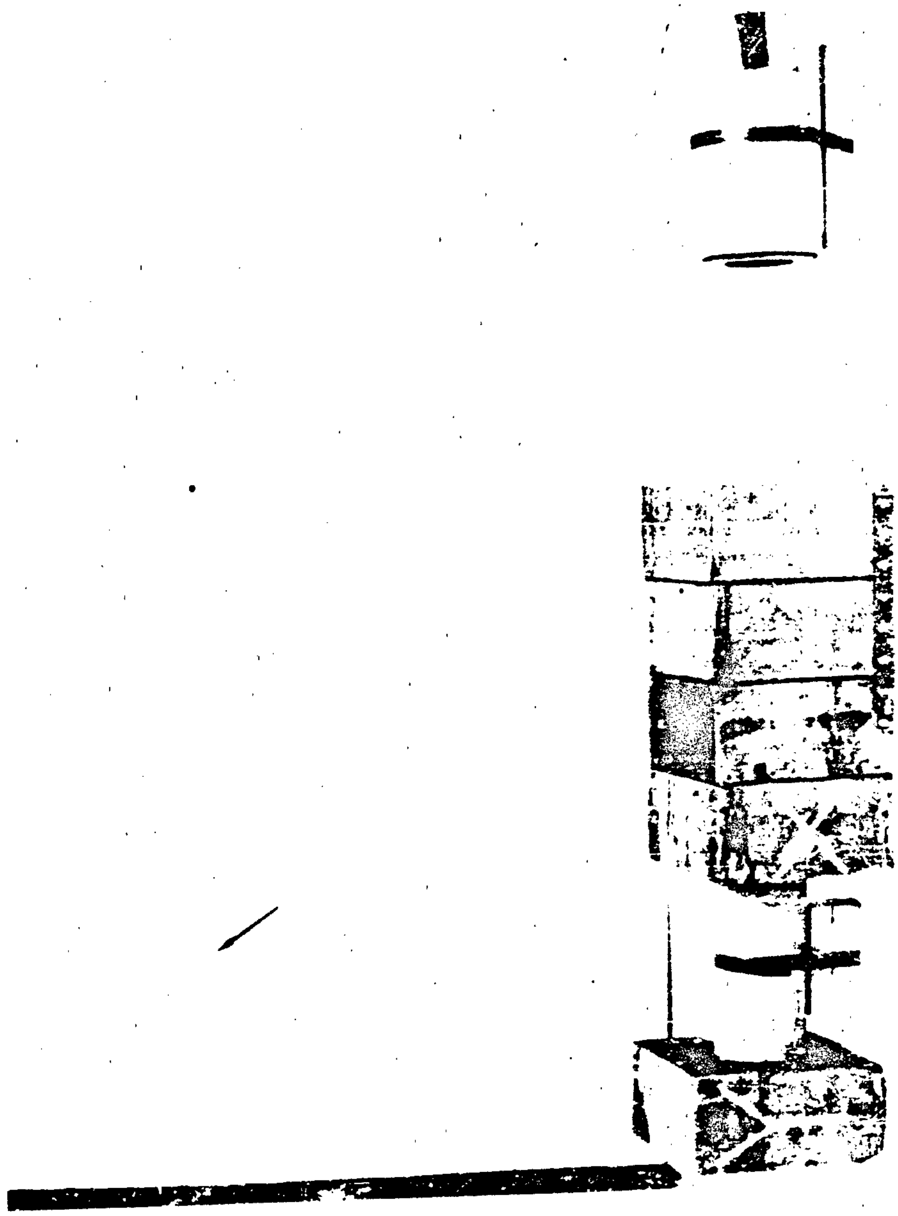


FIG. 8. Arrangement for Firing 105MM Shaped Charge Jets Through Steel Cover Plates Into Composition B Charges with End Confinement.

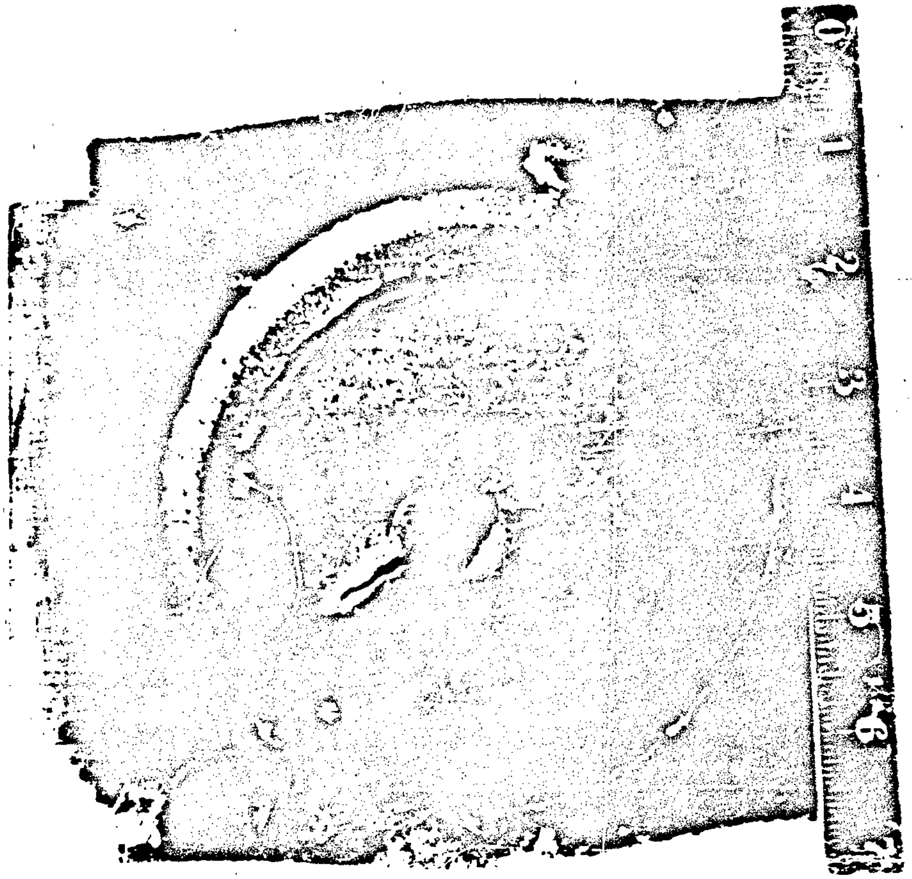


FIG. 9. Impression Into Steel Plate from Initiated Composition B Charge Indicating High Order Initiation.

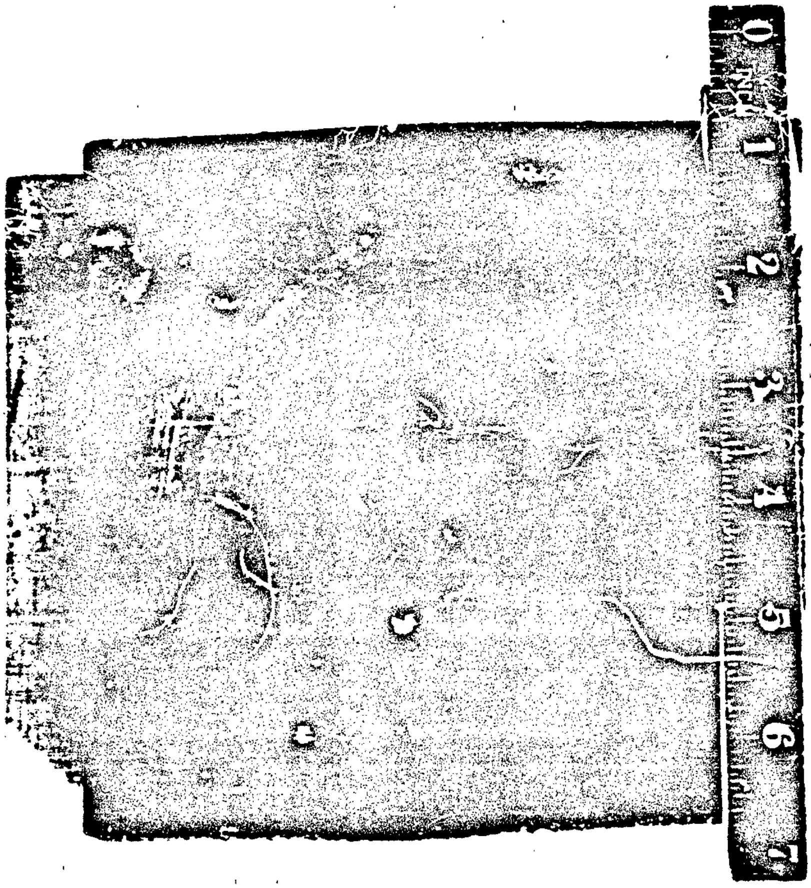


FIG. 10. Impression Into Steel Plate from Initiated Composition B Charge Indicating High Order Initiation.

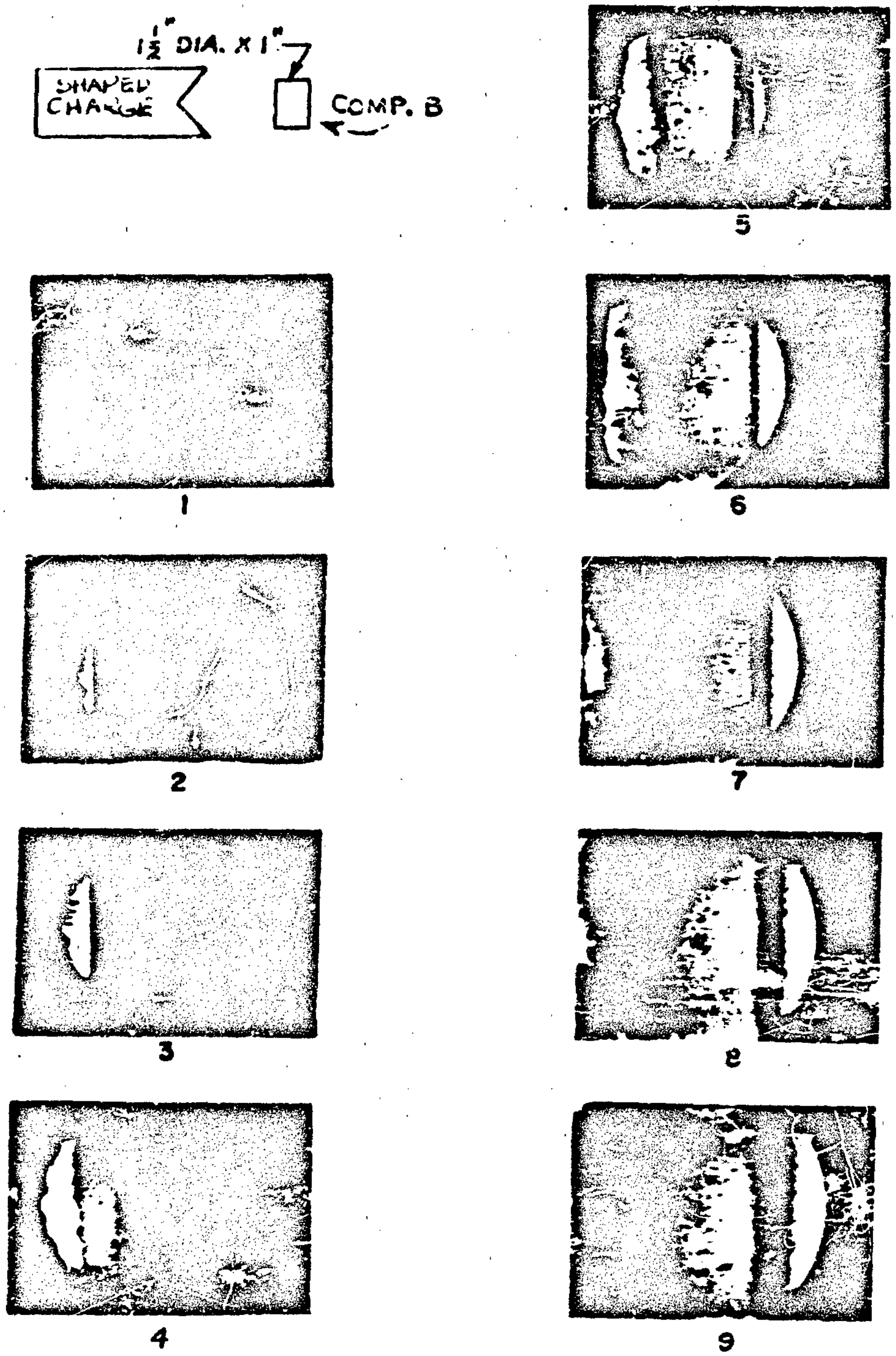


FIG. 11. Initiation of a 1" Long Composition B Charge (W/O Cover Plate) by an M9A1 Shaped Charge Jet.

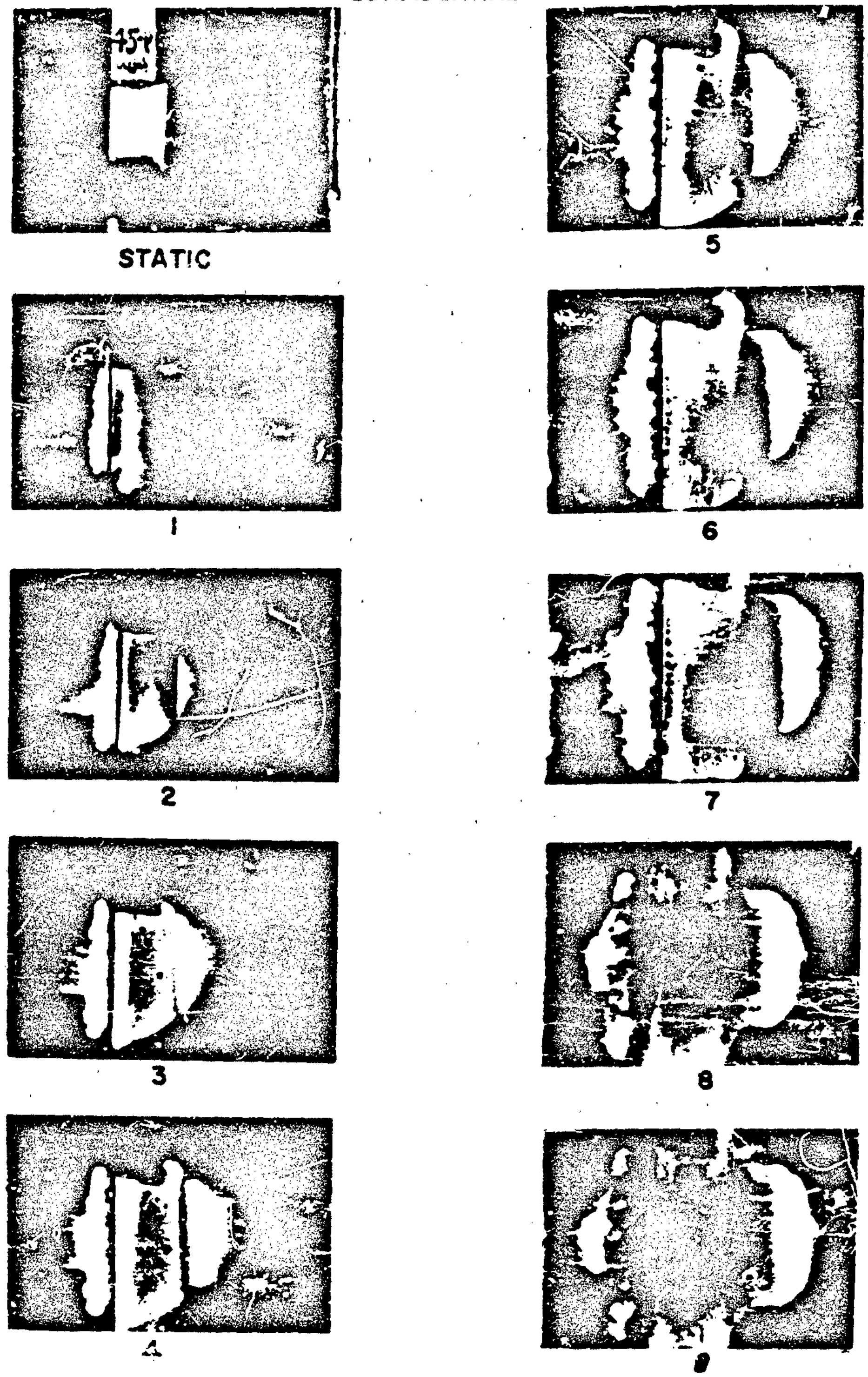


FIG. 12. Initiation of 1" Long Composition B Charge (W/ 1/16" Cover Plate) by an M9A1 Shaped Charge Jet.

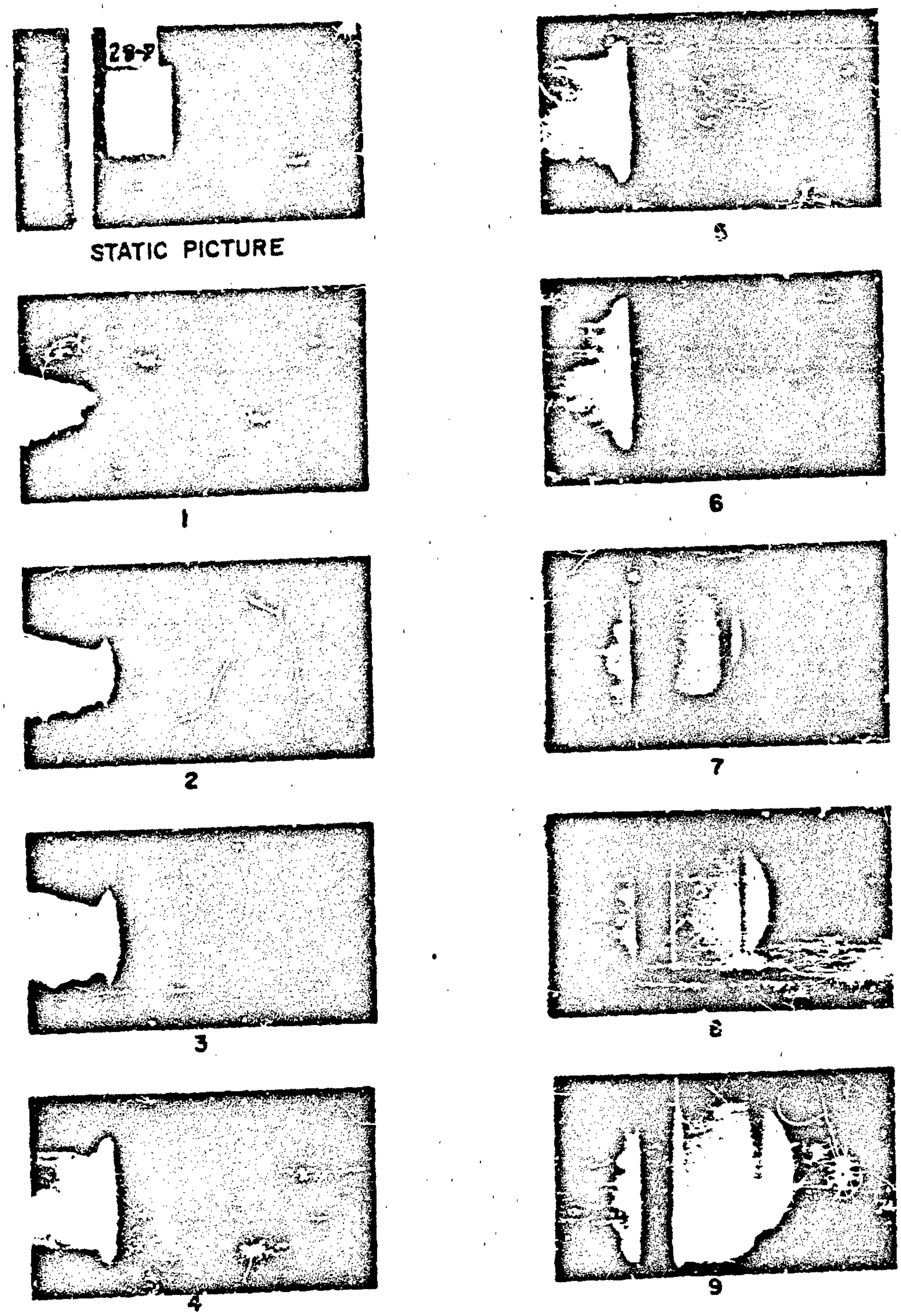


FIG. 13. Initiation of a 1" Long Composition B Charge (W/1/2" Cover Plate) by an M9A1 Shaped Charge Jet.

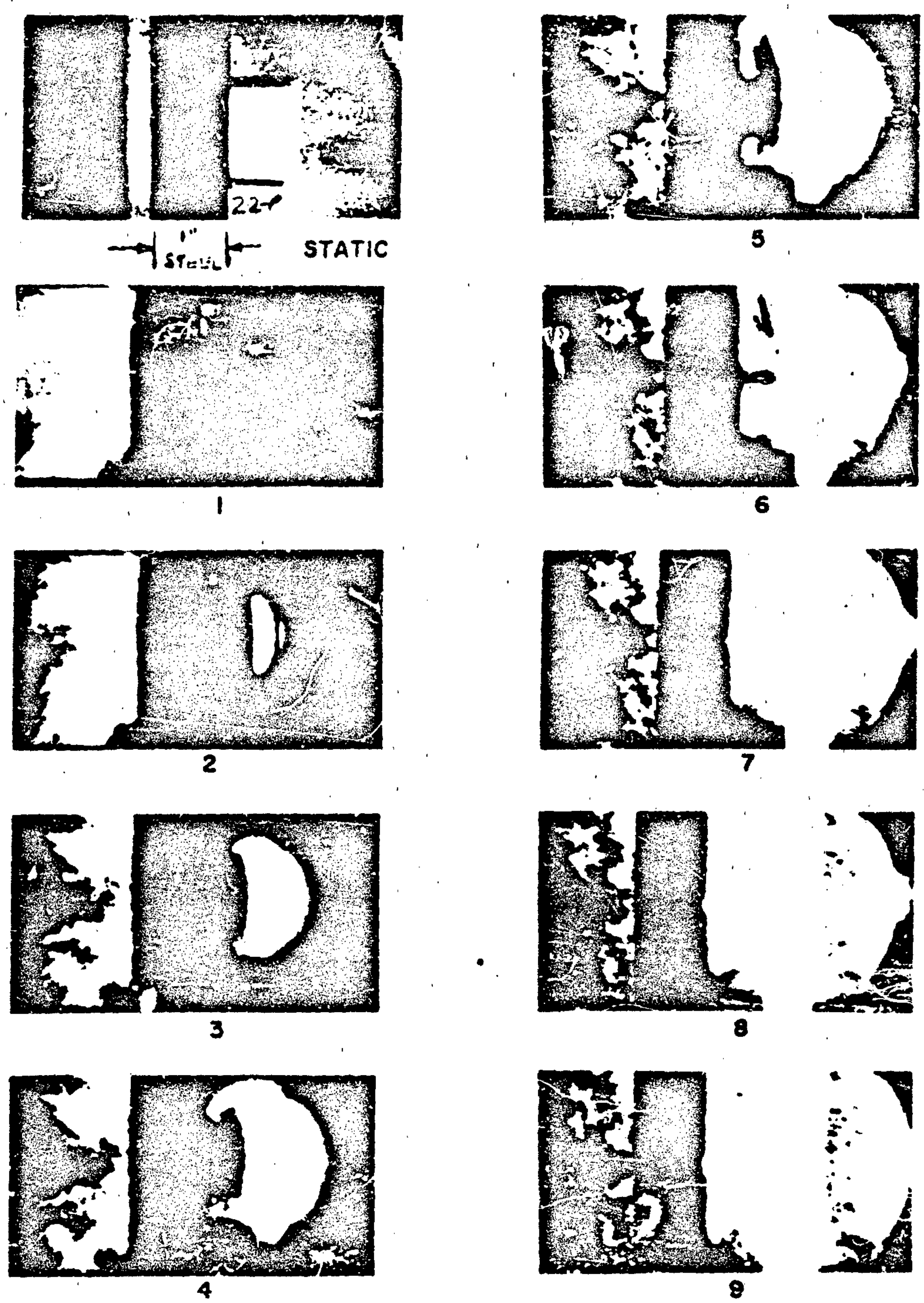


FIG. 14. Initiation of a 1" Long Composition B Charge (W/1" Cover Plate) by an M9A1 Shaped Charge Jet.

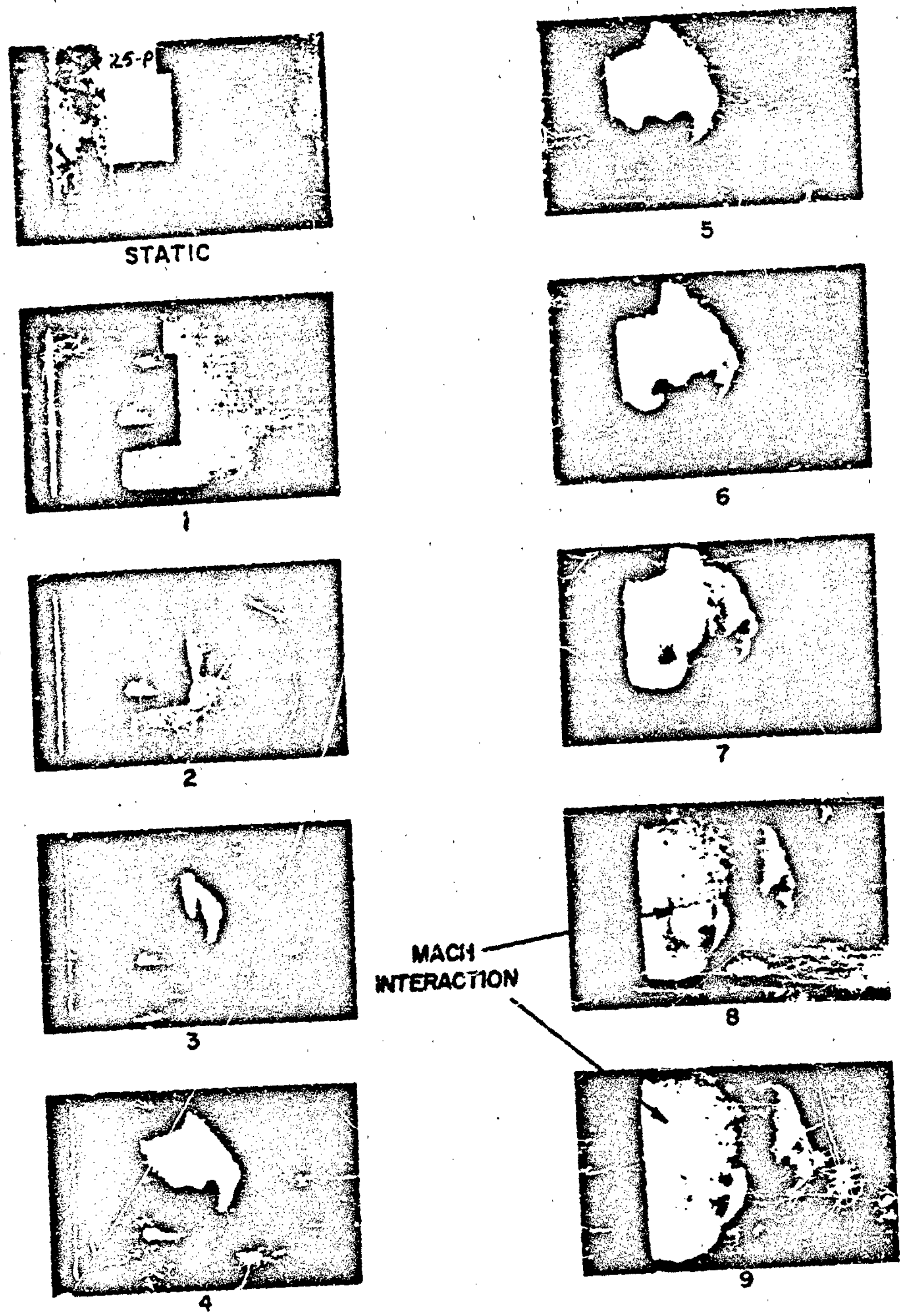


FIG. 15. Initiation of a 1" Long Composition B Charge (W/2" Cover Plate) by an M3A1 Shaped Charge Jet.

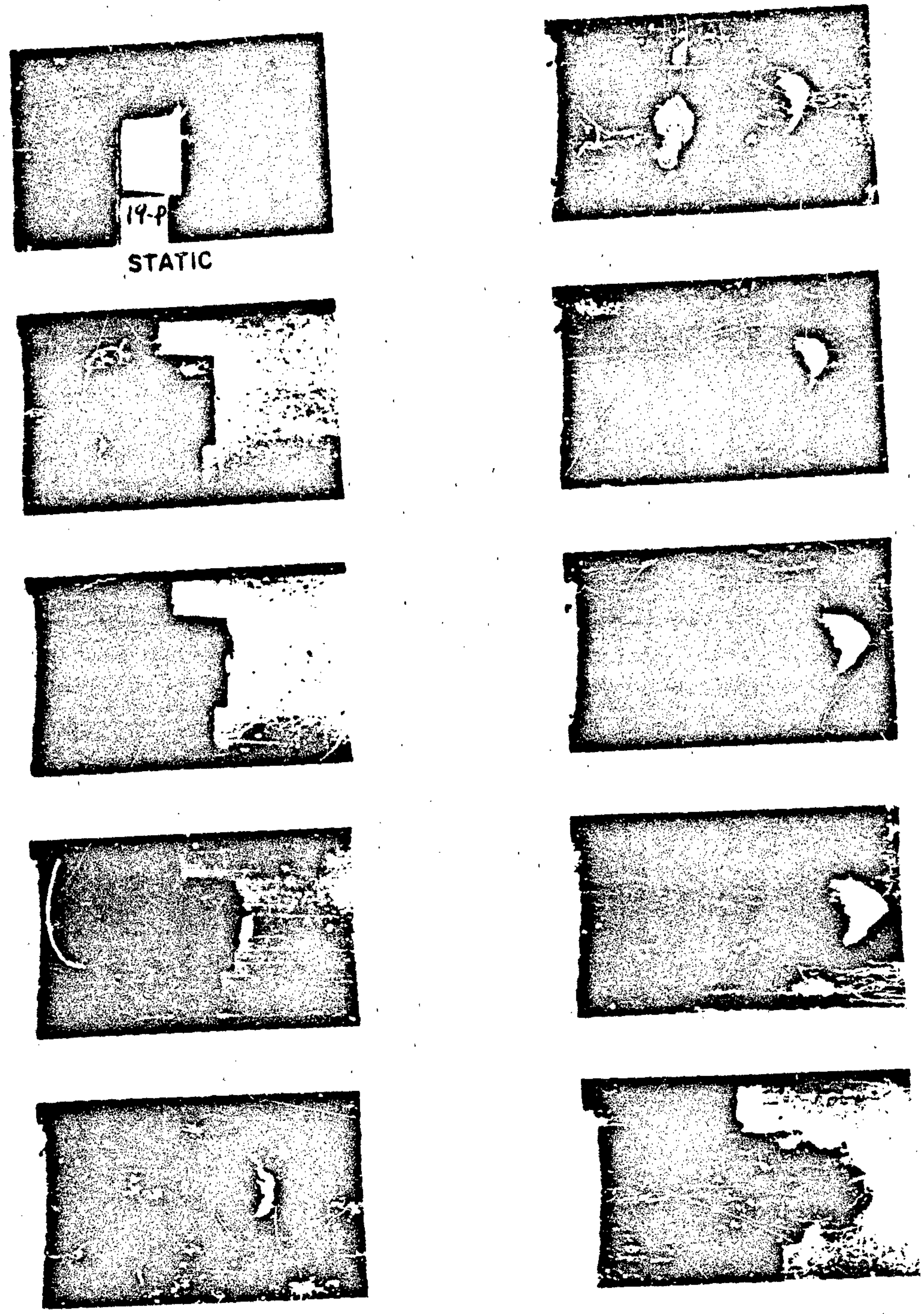


FIG. 16. Failure to Initiate a 1" Long Composition B Charge (W/2" Cover Plate) by an M9A1 Shaped Charge Jet.

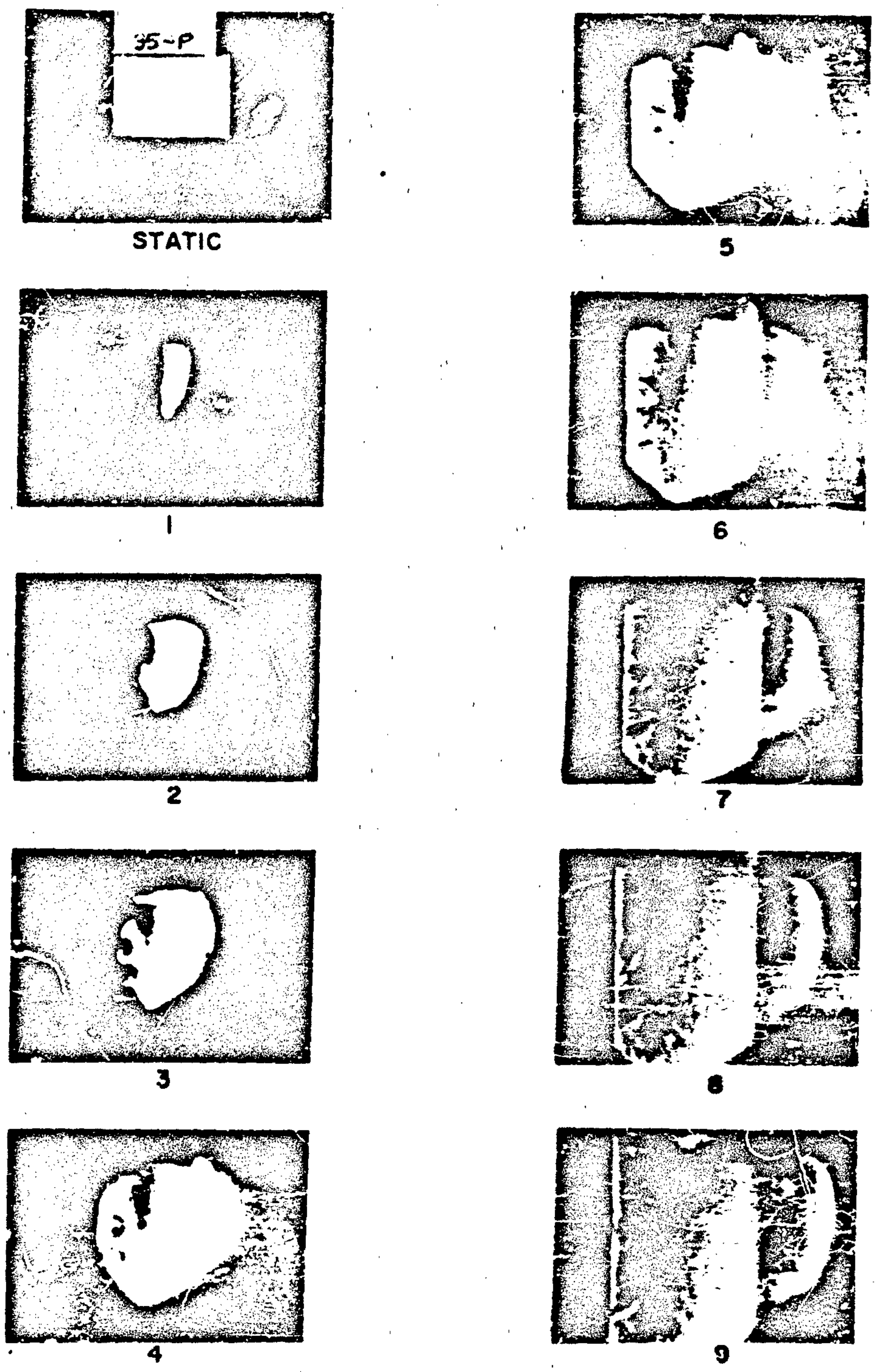


FIG. 17. Initiation of a 2" Long Composition B Charge (W/2" Cover Plate) by an M9A1 Shaped Charge Jet.

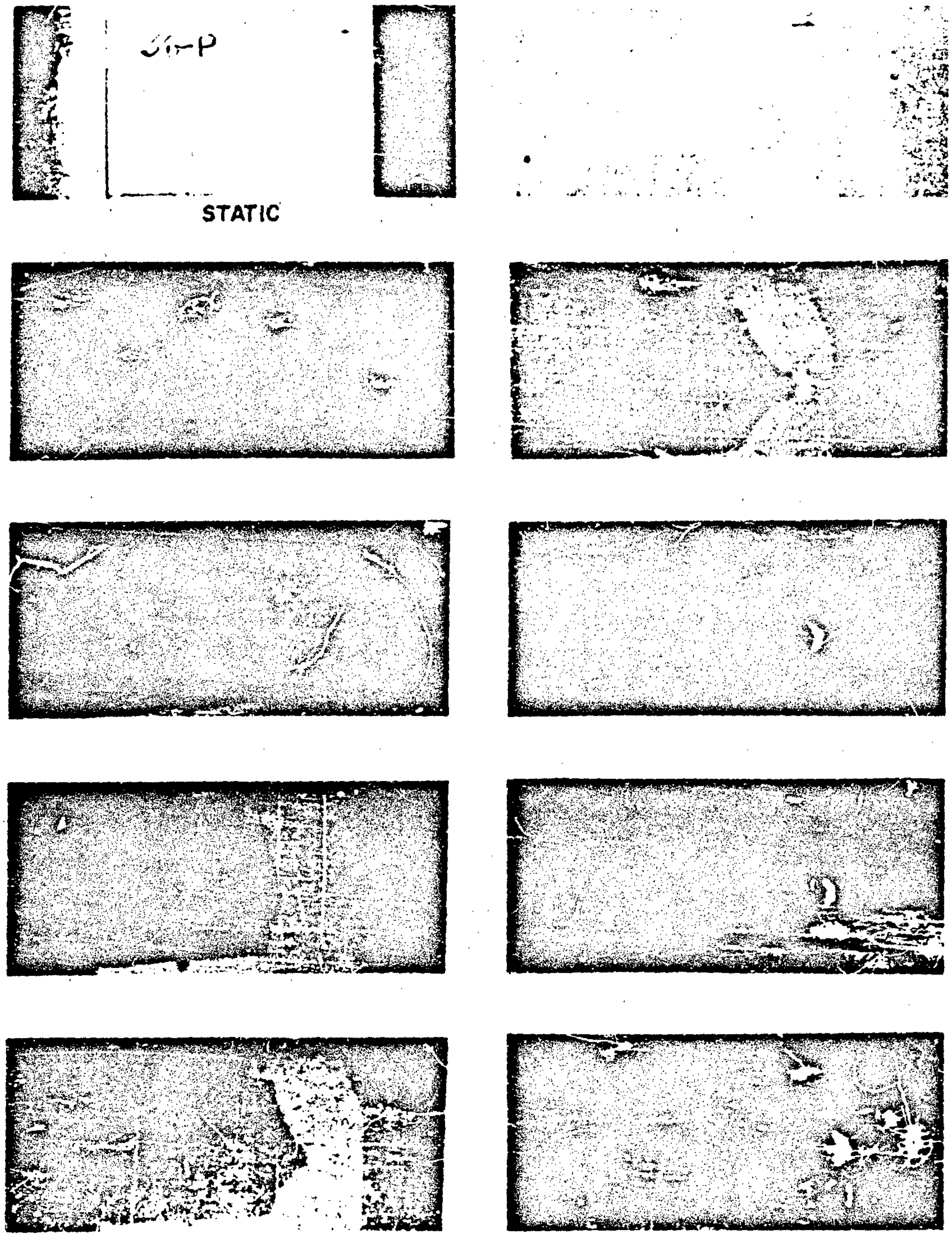


FIG. 18. Failure to Initiate a 2" Long Composition B Charge (W/3" Cover Plate) by an M9A1 Shaped Charge Jet.

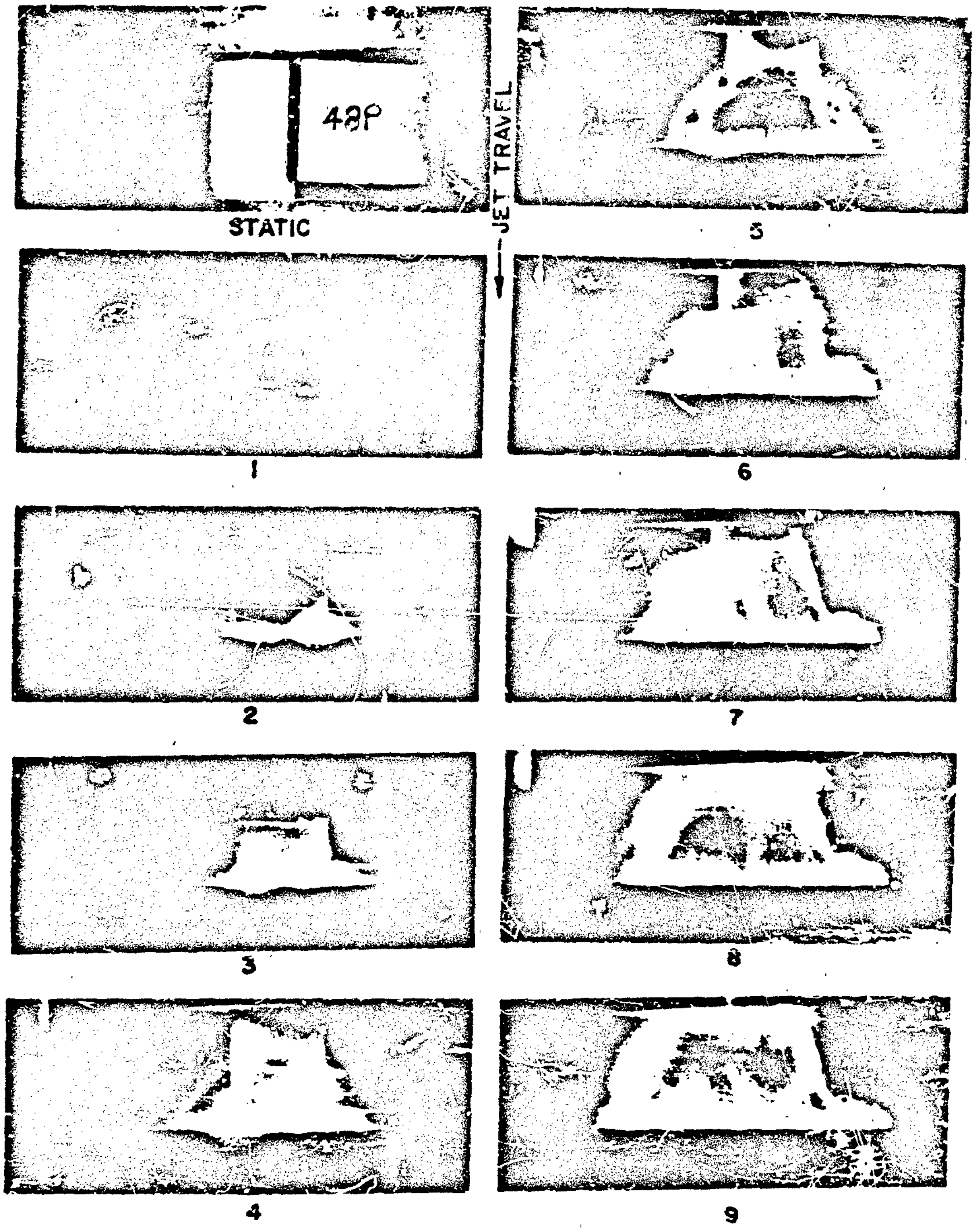


FIG. 19. Initiation of a 2" Long Composition B Charge (W/3" Cover Plate and 1" End-Confining Plate) by an M9A1 Shaped Charge Jet.

RELATION OF PROTECTIVE COVER PLATE THICKNESS TO LENGTH OF EXPLOSIVE CHARGE FOR 0% AND 100% HIGH ORDER INITIATION.

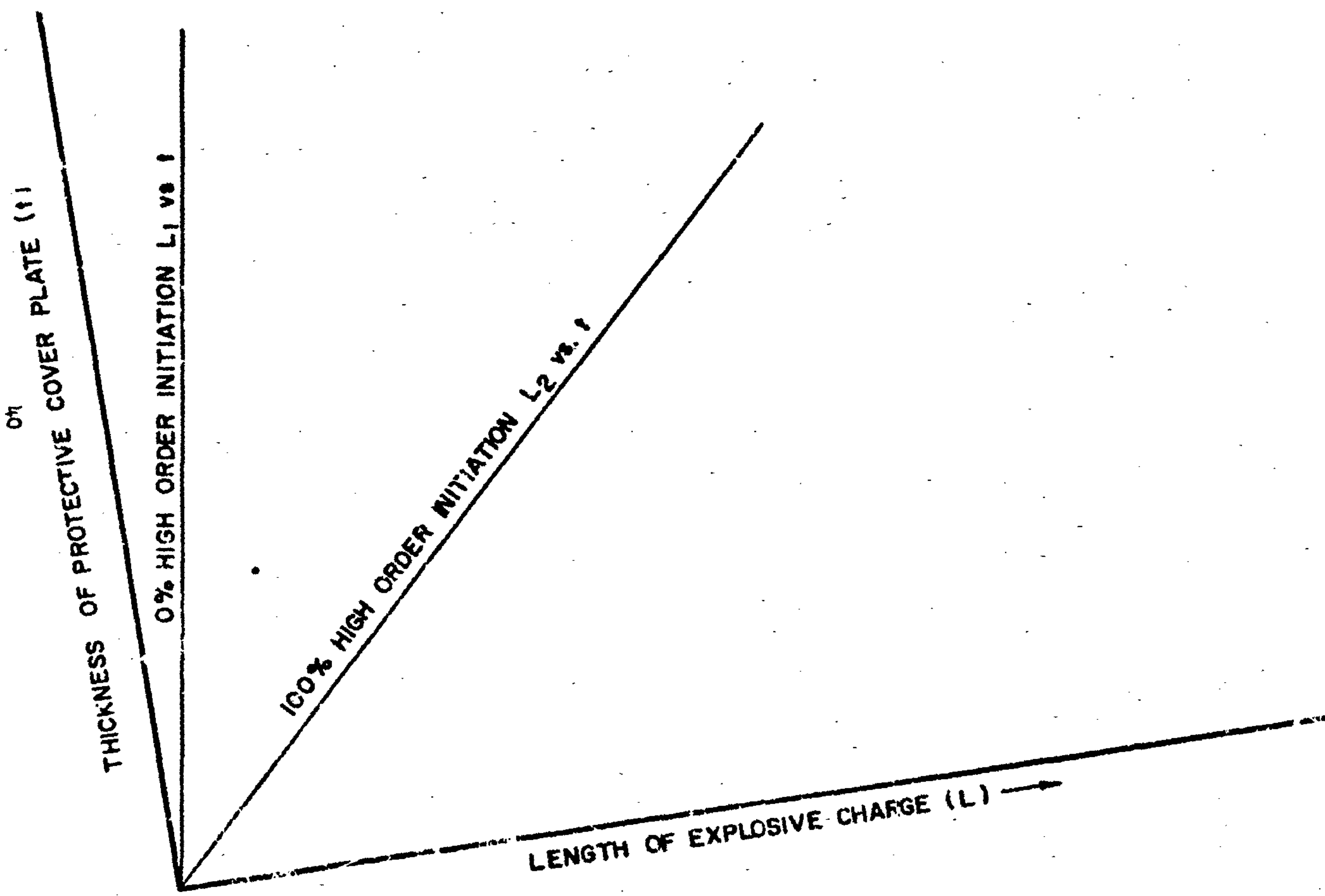


FIGURE 20

[redacted]

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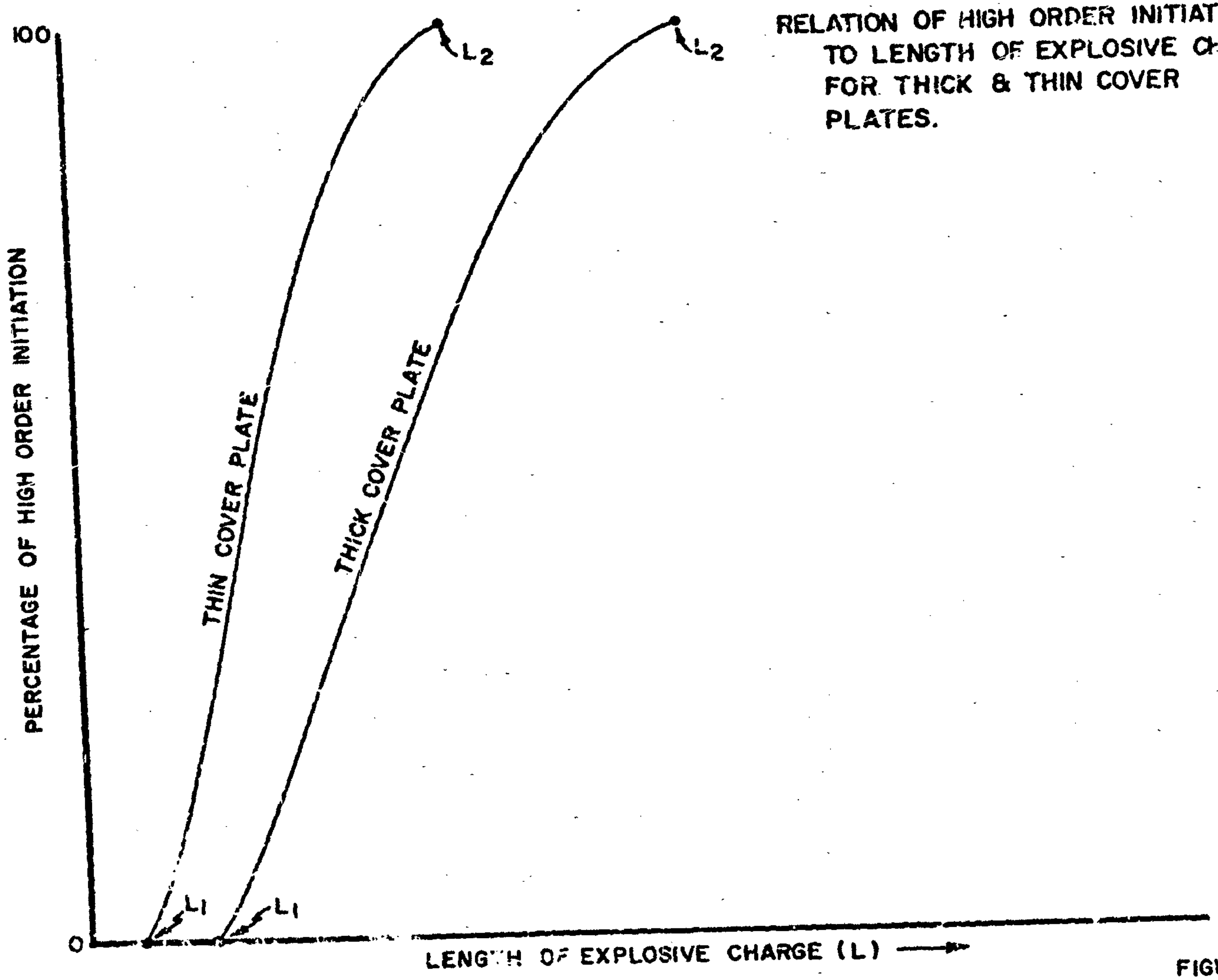

RELATION OF HIGH ORDER INITIATION TO LENGTH OF EXPLOSIVE CHARGE FOR THICK & THIN COVER PLATES.

FIGURE 21

[redacted]

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[redacted]

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RELATION OF PERCENTAGE OF HIGH ORDER INITIATION TO COVER PLATE THICKNESS FOR SHORT & LONG EXPLOSIVE CHARGES.

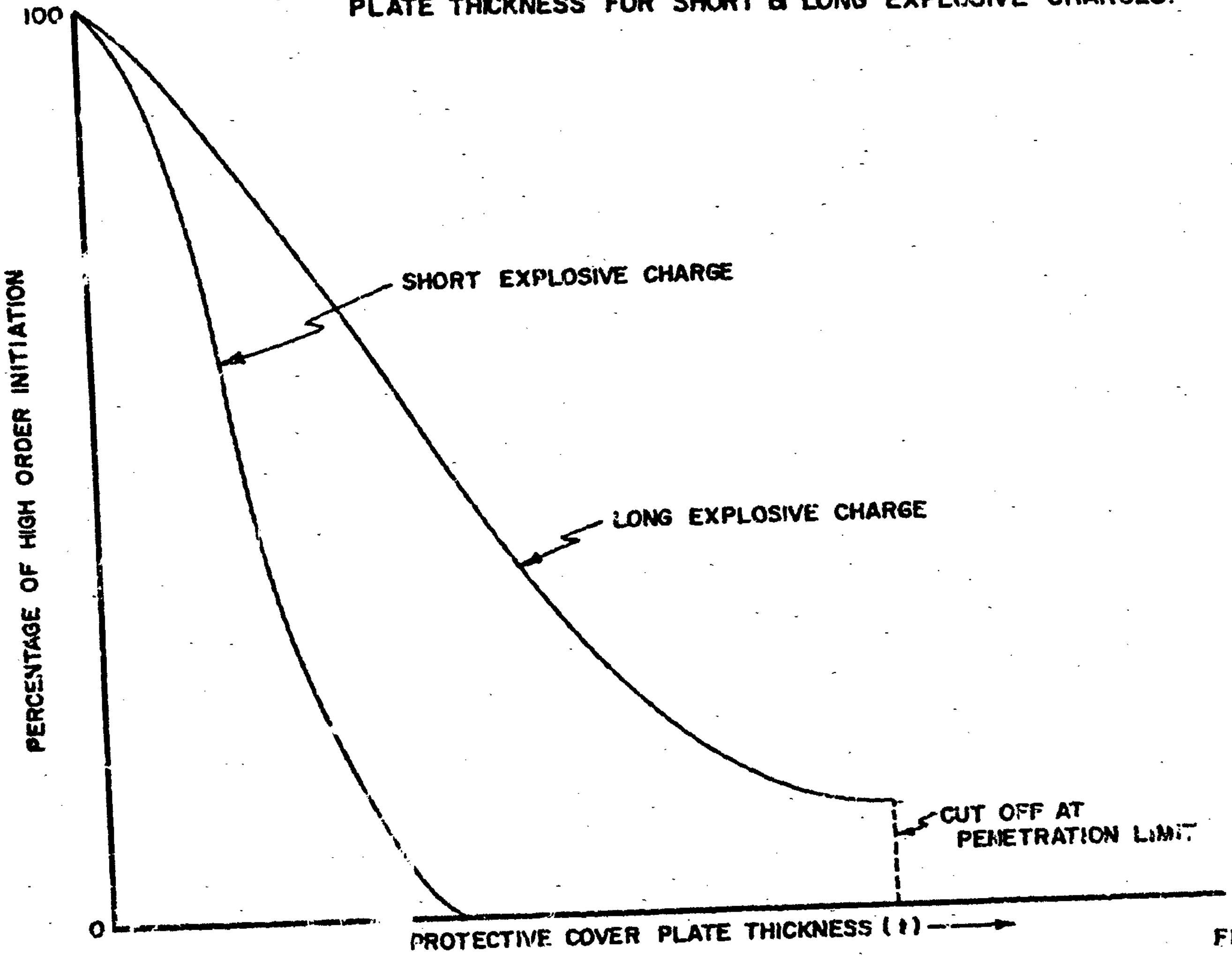

FIGURE 22

[redacted]

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